# Damage detection in frame structures using damage locating vectors

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Research on the use of vibration and modal data to detect, locate and quantify damage in civil structures has vastly increased in the past two decades. Vibration-based damage detection methods are promising because they can detect structural damage quickly and cost-effectively. Once damage appears in a structure it changes the structure's stiffness matrix, which affects the modal behaviour of the structure. Major changes in modal parameters of the structure may thus be due to the existence of damage.

Different detection techniques use different modal parameters. Some methods completely rely on shifts in natural frequencies [1–5] while some others need information on mode shapes, modal damping, etc. [6–11]. Methods based on measuring modal assurance criteria (MAC) [12], modal strain energy [13], modal strain energy decomposition [14,15] and dynamically measured flexibility matrix are few examples.

Dynamically measured modal flexibility matrix as damage detection method is based on the fact that a damaged member alters the flexibility of its related degrees of freedom. The damage member can be located by determining the flexibility matrix using modal parameters. Pandey and Biswas [16] presented a detection and localization method based on changes in the measured modal flexibility of the structure. The results of the numerical and experimental examples of their method showed that it can estimate the damage location and condition using the first few modes only. These examples demonstrated that the modal flexibility method which employs both natural frequencies and mode shapes is more sensitive to damage than other methods based on natural frequencies or mode shapes alone [17,18].

Due to the way flexibility matrix of a structure has been reconstructed using modal data, it does not contain the local information of the system. In other words, flexibility matrix is global and that is why it converges fast with the information of few lower modes. On the other hand, stiffness matrix is local and needs the data of higher modes to converge. So using flexibility matrix to locate damage is not straight forward, especially for structures with complicated geometry e.g. 3D frame structures.

Damage locating vectors (DLV) is one of the best methods that uses dynamically measured flexibility matrix to locate damage. Introduced by Bernal [15], this method can accurately locate single and multiple damage cases in a structure, regardless of its geometry. Damage locating vectors are a set of vectors with a particular property. They cause identical deformations when they are applied to undamaged and damaged state of the structure. As a result, when DLVs are applied to undamaged structure, they induce zero (or relatively small) stress in damage member(s). So using these load vectors and doing linear static analysis of the undamaged structure under these loading and extracting the characterizing stress of all members, the damaged member can be easily spotted as it has zero or relatively small stress compared to other members.

A damage locating vector is defined as the null space of the change in flexibility [19]. However, precise flexibility changes are not the only parameters that can be used to compute DLVs. Bernal [20] stated that even though flexibility cannot be extracted exclusively from output signals in case of operational or ambient vibration, the vectors in the null space can be estimated from output signals without having explicit flexibility matrices. Damage locating vectors can also be extracted from the null space of change in the transfer matrix [21,22].

This study aims to investigate the reliability of DLV method to locate damage member(s) in a 3D frame structure. In order to calculate damage locating vectors, it is assumed that precise modal frequencies and mass normalized mode shapes of the system are available to estimate the flexibility matrices. Some other assumptions are also made that makes this study an ideal case. For example, all degrees of freedom are being measured which is not always possible in real cases. Furthermore, the modal parameters are all numerically generated which makes them perfectly accurate compared to the data extracted from experimental modal testing. The aim is to use this study as a benchmark so that the effect of all these factors can later be studied. So in this case, keeping in mind that certain factors are ideal, the main objective is to examine the ability of DLV in locating single and multiple damage scenarios in all type of members i.e. columns, beams and braces.

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